# SYNTHETIC SEISMOGRAMS FOR CRUSTAL MODEIS IN IRAQ

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## ABSTRACT

Synthetic seismograms are computed for crustal models in Iraq. The velocity models studied are those of Knopoff and Fouda (1975), Bird (1978) and Alsinawi and Al-Heety (1992). A comparison between observed and synthetic seismograms of the models permits an empirical measure of crustal influence. The comparison between observed and synthetic seismograms, for Alsinawi and Al-Heety models, was, in general, good. The poor comparisons may be attributed to the earth structure that may be more laminated those modeled. Alsinawi and Al-Heety models were modified to study the effects of a velocity transition zone at the Moho. The synthetic seismograms of the modified models are favorably compared with observations.

## INTRODUCTION

There have been several geophysical investigations of the crust in Iraq to determine its velocity structure. Seismic body-wave data from measured teleseismic earthquakes have been combined with surface-wave dispersion measurements to determine models of the regional crust and upper mantle structure. Alsinawi and Al-Heety (1992) investigated the crustal structure of Iraq beneath the Iraqi Seismic Network stations using spectral ratio technique and Sp converted phases method. The models af Alsinawi and Al-Heety (1992) show the crust of Iraq beneath those seismic stations to be composed of three layers. Knopoff and Fouda (1975) investigated the crustal and upper mantle structure of the northern part of the Arabian peninsula using surface-wave dispersion data. The models of Knopoff and Fouda (1992) show the crust of that area to be composed of three layers. Bird (1978) studied the crustal structure of the Zagros Mountain Belt using surface-wave dispersion data. He found That The Crustal structure composed of three layers. Refraction models for crust of Iraq are not carried out until now.

The models of Knopoff and Fouda, Bird and Alsinawi and Al-Heety show that the crustal thickness increases toward the eastern parts of Iraq. All the models assume the crustal and the Moho discontinuities to be step function discontinuities in velocity.

Since the arrival time and the shape of a seismic waves provide information concerning the structure and physical properties of the material through which it propagated, many investigators have shown that improvement in interpretation can be realized by modeling amplitude and wave from characteristics of seismograms (Helmberger, 1968 ; Fuchs and Muller, 1971).

This paper examines synthetic seismograms for previously determined Iraq crustal model and investigates the effects of model variations on the synthetics. These results are then compared with observed seismograms as a means of interpretation.

## SYNTHETIC SEISMOGRAM

A synthetic seismogram is a theoretical model of ground motion as recorded by a seismograph. It is composed of several functions used to approximate the processes of the generation and propagation of seismic within the earth as well as through the recording system. These functions analytically describe the source, attenuation, instrumentation, and earth responses where the representation of the synthetic seismogram (SS) is computed from the equation (Nutting, 1985).

$$SS = S*Q*I*E \quad ....(1)$$

where S is the source time function, Q the attenuation, I and E are the response of the instrument and earth and * the convolution operator. The source function S describes the energy output produced by the explosion or earthquake. The intrinsic attenuation operator Q represents a variety of processes which attenuate wave amplitudes and is parameterized by either a constant value for Q or a frequency dependent Q = Q(W). The instrument response I describes the transfer of the ground motion at the sensor to the trace on the seismogram. The earth response E is The computed theoretical ground motion.

Since the response of the instruments, earth and the attenuation are for a delta function source, convolution with any source function gives the proper recorded motion for that particular source.

The attenuation function Q as used serves two purposes (Leong, 1976). Firstly, it shapes and tapers the system transfer function leading to a reduction in leakage through transaction. Secondly, this damping factor permits of a physical association with the passage of a particular wave-type, through an elastic section in the ray-path. Thus, the total system transfer function is given simply by :

$$X_k = \exp(-\pi \; f_k \; t^*) . I_k . C_k \quad ....(2)$$

where;

$X_k$ is system transfer function at frequency point Fk; exp (- $f_k$ t*) is attenuation function, f= w/2π = frequency (hz), $t^* = T/Q_{av}$, where T= total travel time (sec) from source to recording station, and $Q_{av}$ = average equality factor, for particular wave type and ray-path; $I_k$ is instrument transfer function at frequency point $f_k$, $C_k$ is crustal transfer function for a particular wave-type at frequency point $f_k$, k=0,1,.....N/2 where $f_k$ = K/N t

Next, let $X_k$ be the complex conjugate of the array such that $N=2^m$. By symmetry, the inverse fourier transform.

$$N = \frac{1}{N} \sum_{K=0}^{N/2} X_k( j2 \pi \iota K/N) \quad j= -1 \ldots (3)$$

$\iota = 0,1,\ldots,N-1$

returns the trace signal sough (Bath, 1974).

## DATA ACQUISITION

Seismograms of shallow earthquakes are not favored because they are generally complicated due to intricate source processes and crustal effects around the source (Kurita, 1976). As already noticed in Kurita (1973) the crustal effects are mostly confined to about 40 sec following the onset of the P-phase, while the effects of the layering down to a depth of about 40 and 100 sec.

Since S waves are usually much contaminated by preceding and later phases, we confine ourselves to teleseismic P waves from deep earthquakes. In order to make comparisons easier. we prefer records of single shocks which are as free from noise as possible. We restrict our comparisons to the Z-component.

According to the discussion mentioned above, the events recorded by station of Iraqi Seismic Network (Fig. 1) were used. The recordes in Figure 2 are of deep earthquakes for which the information are given in Table (1).

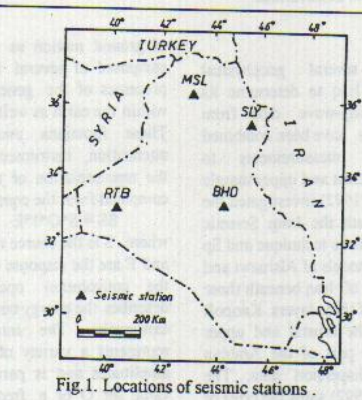


Fig.1. Locations of seismic stations

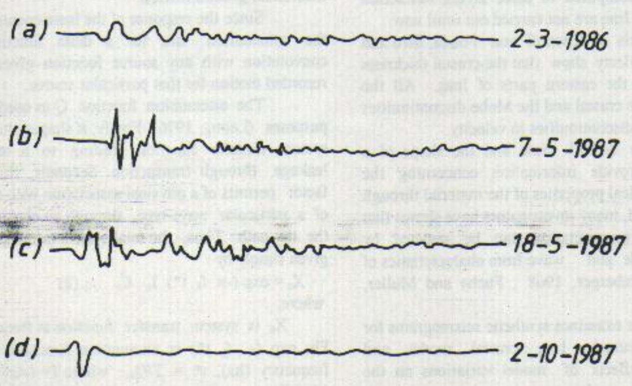


Fig.2. Records of the events used in this study,(a)at BHD station (b) at MSL station (c) at SLY station (d) at RTB station.

Table 1: List of Earthquakes.

| Date Y | M | D | Origin Time H | M | S | Coordinate Lat. | Long. | Depth Km | M | Δ Deg. | Station | Region |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1986 | 02 | 03 | 20 | 47 | 35.3 | 27.7° N | 139.5°E | 508 | 5.8 | 82.5 | BHD | Bonin Island |
| 1987 | 05 | 07 | 03 | 05 | 49.1 | 46.7° N | 139.2°E | 430 | 6.0 | 68.0 | MSL | Near East Coast of USSR |
| 1987 | 05 | 18 | 03 | 07 | 34.13 | 49.2° N | 147.6°E | 542 | 6.1 | 70.0 | SLY | Sea of Okhtsk |
| 1987 | 10 | 02 | 02 | 38 | 27.8 | 27.3° N | 139.9°E | 464 | 5.5 | 79.5 | RTB | Bonin Island |

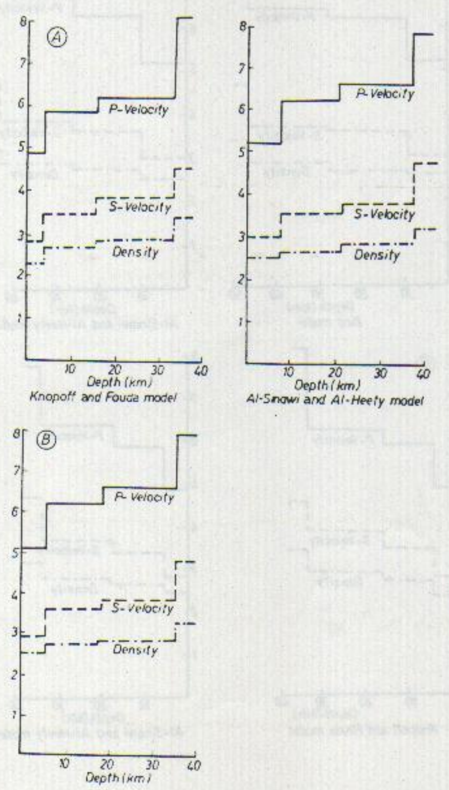


Fig. 3. (A) Crustal models beneath BHD station. (B) Al-Sinawi and Al-Heety model beneath MSL station. Velocities are measured in Km/sec and density in gm/cm$^3$.

## COMPUTATION OF SYNTHETIC SEISMOGRAMS

The vertical component of the ground is calculated as an inverse Fourier transform of product of the frequency response of the model with the instrumental response and the attenuation along the wave path. The source effect is neglected.

The effect of attenuation is taken into account by incorporating a factor exp (- f $T_p/Q_p$) where f is frequency, $T_p$ and $Q_p$ are the travel time and an average of Q along the wave path for p wave respectively. $T_p/Q_p$ is taken as 2.0. This estimate is selected by a trial-and error procedure in an attempt to fit the feature of the undulations of synthetic seismograms, reasonably well with that of the records. $T_p$.s are estimated according to JB tables.

Synthetic, vertical component seismograms were computed for various velocity-depth models of Iraq by the Haskell-Thomson matrix, using the computer program developed by Langston (1976). The models investigated are those of Knopoff and Fouda (1975), Bird(1978) and Alsinawi and Al-Heety (1992). These models are shown in Figures 3 And 4. All crustal velocity models are characterized by relatively sharp discontinuities at the Moho and within the crust. The different velocity models result in different characteristic on synthetic seismograms. Synthetic seismograms computed for each model are shown in Figures 5 and 6.

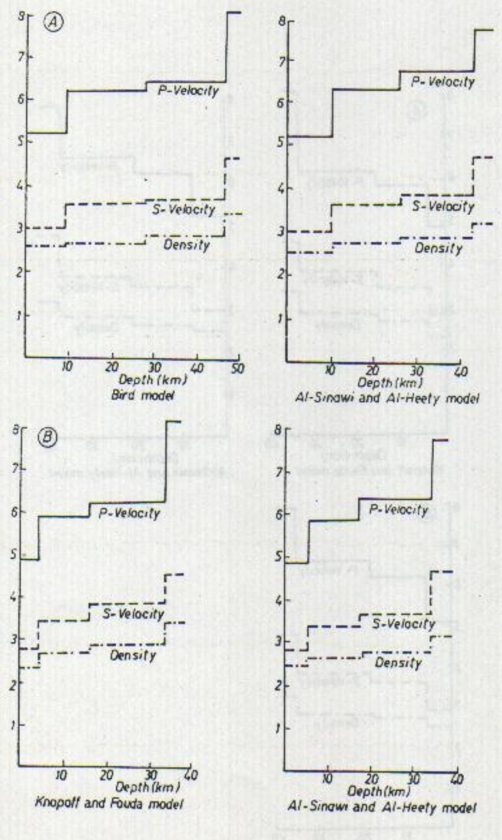


Fig.(4). (A) Crustal models beneath SLY station. (B) Crustal Models beneath RTB station. Velocities are measured in Km/sec and density in gm/cm$^3$.

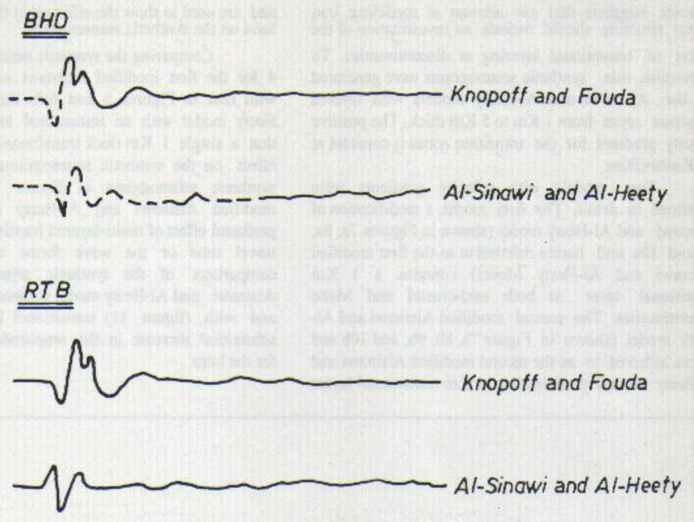


Fig.(5). Synthetic seismograms for Knopoff and Fouda model and Al-Sinawi and Al-Heety model beneath BHD and RTB stations.

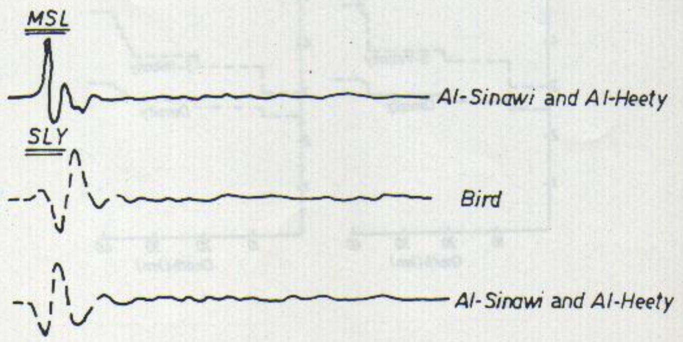


Fig.(6). Synthetic seismograms for Al-Sinawi and Al-Heety model beneath MSI station and for Brid model and Al-Sinawi and Al-Heety model beneath SIY station .

## EFFECTS OF TRANSITIONAL LAYERING

Helmberger (1968) showed the Moho discontinuity modeled as a layered transitions. This evidence suggests that any attempt at modeling Iraq crustal structure should include an investigation of the effects of transitional layering at discontinuities. To accomplish this, synthetic seismograms were generated for the Alsinawi and Al-Heety models with layered transition zones from 1 Km to 5 Km thick. The positive velocity gradient for the transition zones is constant at 0.2 Km/sec/Km.

Two models with velocity gradients were examined in detail. The first model, a modification of Alsinawi and Al-Heety model (shown in Figures 7a, 8a, 9a and 10a and herein referred to as the first modified Alsinawi and Al-Heety Model) contains a 1 Km transitional layer at both mid-crustal and Moho discontinuities. The second modified Alsinawi and Al-Heety model (shown in Figure 7b, 8b, 9b, and 10b and herein referred to as the second modified Alsinawi and Al-Heety model) contains five -1 Km transitional layers at the Moho discontinuity. These two models are representative of the several gradient structures studied and are used to show the effects that the transition zones have on the synthetic seismograms.

Comparing the synthetic seismograms in Figure 4 for the first modified Alsinawi and Al-Heety model with that in Figures 5 and 6 for the Alsinawi and Al-Heety model with no transitional layering, we can see that a single 1 Km thick transitional layering has little effect on the synthetic seismograms. Conversely, the synthetic seismograms in Figure 7 for the second modified Alsinawi and Al-Heety model reveal the profound effect of multi-layered transition zone on either travel time or the wave forms of the waves. A comparison of the synthetic seismograms for the Alsinawi and Al-Heety model without (Figures 5 and 6) and with (figure 11) transitional layering reveals a substantial increase in the amplitude of the wave form for the later.

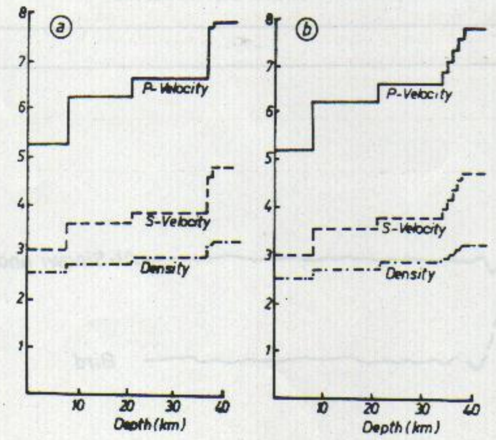


Fig.(7). Modified Al-sinawi and Al-Heety crustal models beneath BHD station.
(a) crustal model with single transitional layer at the Moho discontinuity.
(b) crustal model with five transitional layer at the Moho discontinuity.
Velocities are in km/sec and density in gm/cm$^3$.

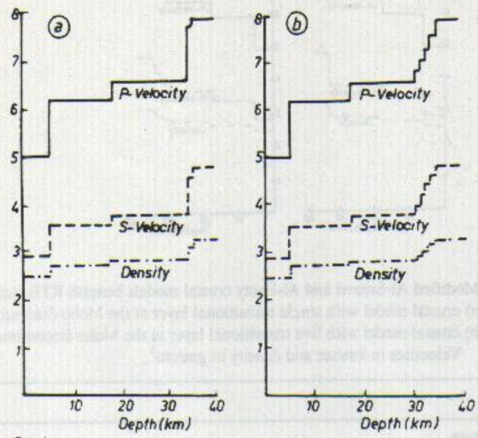


Fig.(8). Modified Al-Sinawi and Al-Heety crustal models beneath MSLstation.
(a) crustal model with single transitional layer at the mid crustal and Moho discontinuies.
(b)crustal model with five transitional layer at the Moho discontinuity.
Velocities are in km/sec and density in gm/cm$^3$.

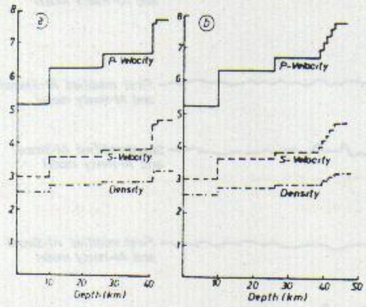


Fig.(9). Modified Al-Sinawi and Al-Heety crustal models beneath SLY station.
(a) crustal model with single transitional layer at the Moho discontinuity.
(b) crustal model with five transitional layer at the Moho discontinuity.
Velocities in km/sec and density in gm/cm3 .

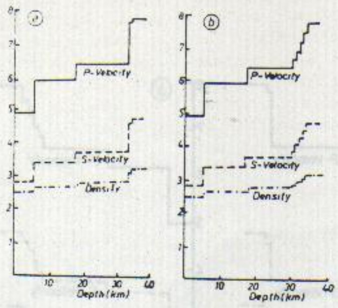

Fig.(10). Modified Al-Sinawi and Al-Heety crustal models beneath RTB station.
(a) crustal model with single transitional layer at the Moho discontinuity.
(b) crustal model with five transitional layer at the Moho discontinuity.
Velocities in km/sec and density in gm/cm$^3$ .

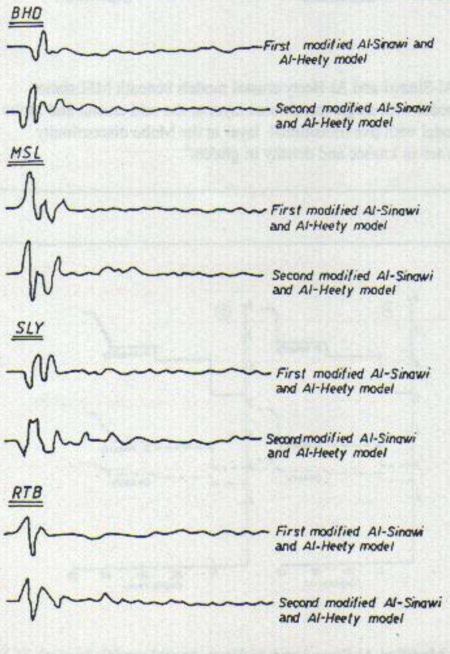


Fig.(11). Synthetic seismograms for modified Al-Sinawi and Al-Heety crustal model beneath Iraq Seismic Network stations.

## COMPARISON OF SYNTHETIC AND OBSERVED SEISMOGRAMS

Seismograms recorded by the Iraqi Seismic Network for four deep teleseismic earthquakes were compared with the previously discussed synthetic seismograms as a means of interpretation. The comparison travel-time comparison and wave form comparison. Although the magnification of the seismogram and the shapes of the pulses by the sources are not known, we can make qualitative comparison by modeling some of the most prominent amplitude, and arrival time features of the seismograms. The synthetic seismograms for the used crustal models were compared with the observed seismograms (Figures 12, 13, 14 and 15). In general, the observed stronger arrivals matches the synthetic arrivals. Wave form comparison of the synthetic and observed seismograms indicates generally marked disgreements. The synthetic seismograms for the Knopoff and Fouda, Bird, and Alsinawi and Al-Heety and first and second modified Alsinawi and Al-Heety models are shown with the observed seismograms in Figures 12, 13, 14 and 15. The observed data, in general, have lower period and more complicated wave shape than the synthetics. This may be due to more complicated source functions and/or an earth structure with undulating or slightly dipping layers which are more laminated and laterally discontinuous than those modeled.

In general, there is agood correlation between observed and synthetic amplitudes (second modified Alsinawi and Al-Heety). A comparison of synthetics for Alsinawi and Al-Heety and modified Alsinawi and Al-Heety model (Figures 5,6 and 11) shown that a step in velocity, representing a sharp discontinuity, develops a small amplitude compared to a larger amplitude resulting from a positive velocity gradient at the discontinuity.

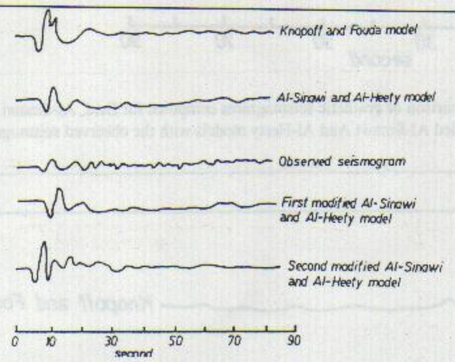


Fig.(12). Comparison of synthetic seismograms computed for Knopoff and Fouda, Al-Sinawi and Al-Heety and modified Al-Sinawi and Al-Heety and observed seismogram at BHD station.

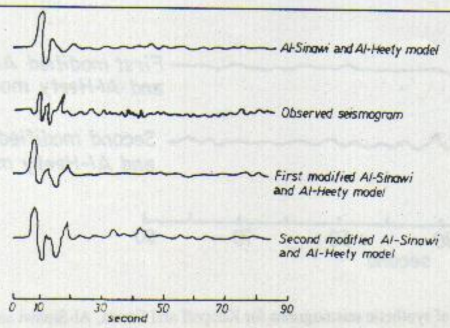


Fig.(13). Comparison of synthetic seismograms computed for Al-Sinawi and Al-Heety model and modified Al-Sinawi And Al-Heety models with the observed seismogram at MSL station .

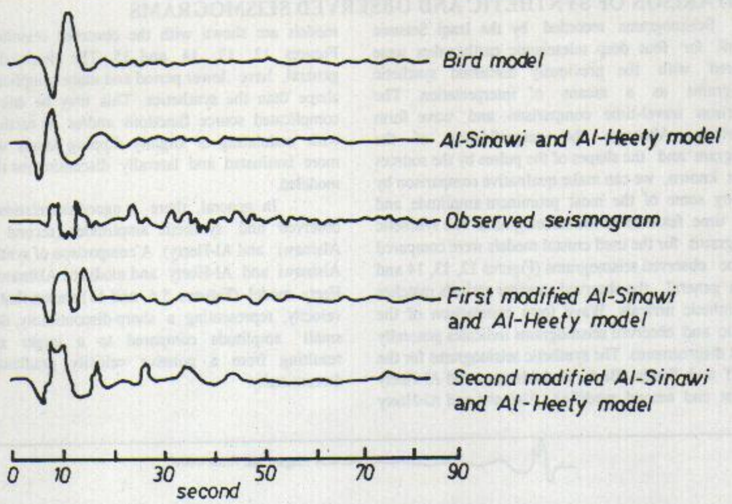


Fig.(14). Comparison of synthetic seismograms computed for Brid, Al-Sinawi and Al-Heety and modified Al-Sinawi And Al-Heety models with the observed seismogram at SLY station .

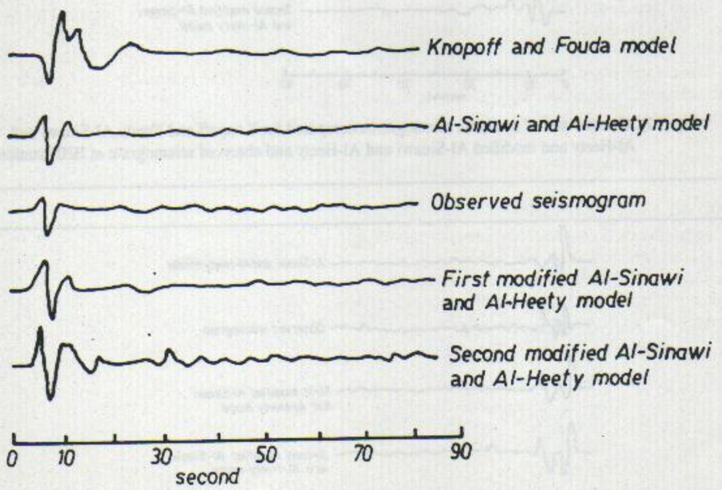


Fig.15. Comparison of synthetic seismograms for Knopoff and Fouda, Al-Sinawi and Al-Heety and modified Al-Sinawi And Al-Heety models with the observed seismogram at RTB station .

## SUMMARY OF RESULTS

Traditional seismic interpretation techniques have determined velocities and layer structure based primarily on travel times. However, an interpretation based only on the travel times of waves is not unique for layered media. By modeling amplitude and wave form characteristics of seismograms, investigators can improve interpretations and refine models of crustal structure.

The objective of this work was to illustrate the effects of various seismic velocity distributions on the resulting seismic record using synthetic seismograms. Synthetics were computed for the Knopoff and Fouda, Bird and Alsinawi and Al-Heety models for Iraq. Synthetic seismograms were compared with the observed seismograms of deep earthquakes recorded by Iraqi Seismic Network Stations. Synthetics for Alsinawi and Al-Heety model show, in general, good correlation with the observed data, while the synthetics for Knopoff and Fouda and Bird models show poor correlation. This may be attributed to the fact that the Knopoff and Fouda and Bird models represent regional crustal models, with the Alsinawi and Al-Heety models represent local crustal models beneath the seismic stations.

Modified Alsinawi and Al-Heety models were used to study the effects of a velocity transition zone at the Moho. It was found that the velocity-transition zone produced a larger amplitude compered with the velocity step. Synthetics for modified Alsinawi and Al-Heety models show better correlation with observed data compared with synthetics of Alsinawi and Al-Heety models.

Wave form comparisons of the synthetics and observed seismograms indicated marked disagreements. This may be due to an earth structure with undulating or slightly dipping layers which are more laminated and laterally discontinuous than those modeled.

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